The prosodic effects on the fronting of alveolar consonants in Korean

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Introduction

The impressionistic observations of the fronting of Korean alveolar consonants

- Korean alveolar consonants are often produced interdentally, with the tongue protrusion when they are followed by a homorganic consonant ([tt], [nn], [nt]).

  e.g. 갔다, 갔나, 간다

- The fronting of alveolar consonants also takes place in prosodic domain-final position.

The articulation of alveolar consonants in Korean

- 발음 '<u>간</u> 데'
- https://www.youtube.com/watch?v=8fhDMg6taNc

The articulation of alveolar consonants in Korean

- 발음 '순대'
- https://www.youtube.com/watch?v=H5YYSrHwAwU

Research Questions

What is the underlying mechanism of the fronting of /t, n/?

1. Is this fronting of Korean alveolar consonants induced by long duration? Is the segmental duration also correlated with the degree of protrusion? Do speakers exhibit different tongue contours for geminates compared to singletons?

2. Do Korean speakers employ this articulatory strategy to signal the prosodic domain-final sounds? Does the degree of the fronting vary according to the size of the prosodic domain? Is a greater magnitude of fronting observed at higher prosodic boundaries?

Purposes of the study (1)

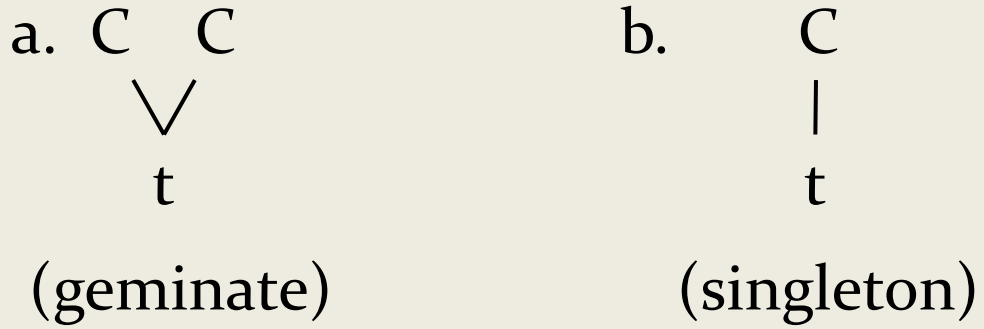
- To investigate the relationship between the fronting and gemination:

  → Gemination involves the articulatory fronting of alveolar consonants in Korean, using ultrasound imaging of tongue.

  → This study raise a question concerning the possibility that singletons and geminates may have different targets for place of articulation.

Geminate vs. Singleton

Prosodic length analysis of geminates
(Clements and Keyser, 1983)

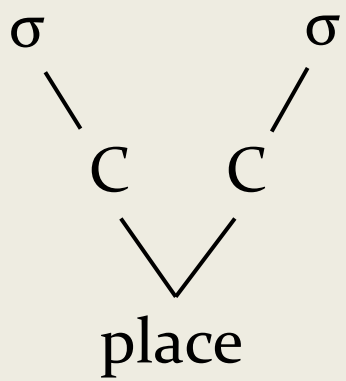


Coda condition (Ito, 1989: 224)

* C] σ
    |
  place

- Gemination: /kir-ta/ ‘cut-past’ ⟶ [kitta]
- Place assimilation: /kam-ta/ ‘chew-past’ ⟶ [kanda]

Geminates in this study



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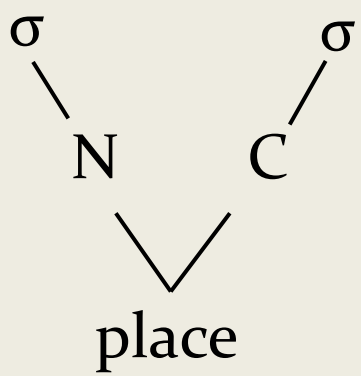

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Purposes of the study (2)

- To show whether alveolar consonants in the higher prosodic domain-final position exhibit more fronting than those in the lower prosodic domain-final position, using ultrasound imaging of tongue.

Domain-final lengthening(1)

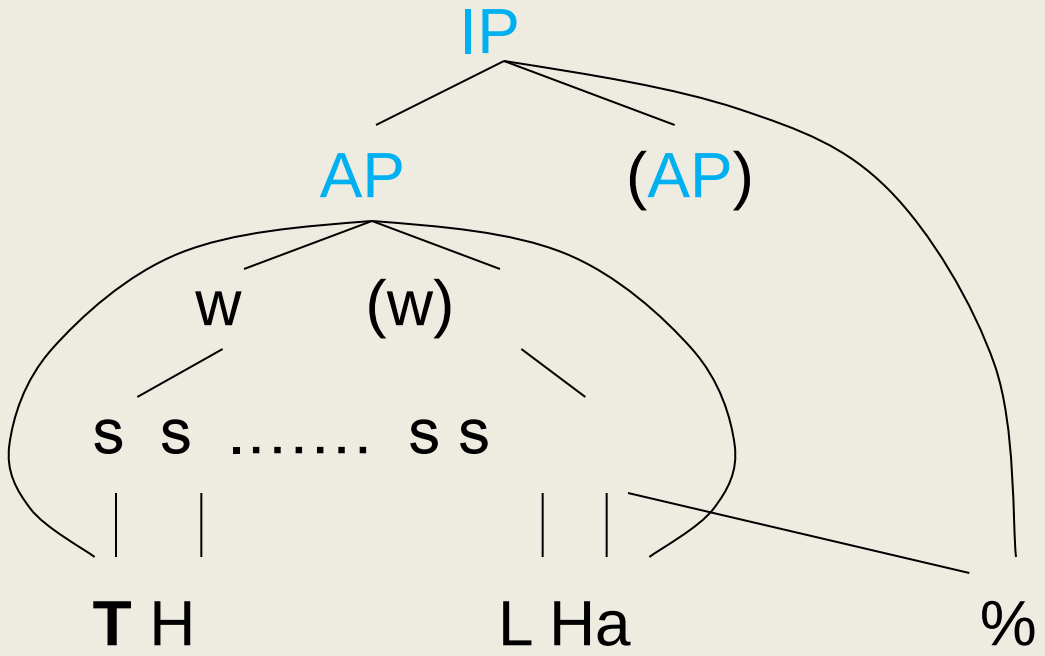
- Domain-final lengthening refers to a temporal expansion of segment(s) in a word at the prosodic juncture compared to those in a word occurring domain-medially (Lindblom, 1968; Oller, 1979; Wightman et al., 1992).
- The lengthening effect has been found to be more robust before a larger prosodic boundary than a smaller one (Edwards et al., 1991; Berkovits, 1993; Byrd et al., 2006; Turk and Shattuck-Hufnagel, 2007; Katsika, 2016).

Domain-final lengthening(2)

- While the temporal and acoustic effect of prosodic boundary across world's languages has been extensively documented in the literature, the articulatory implementation of final lengthening in Korean is not understood thoroughly.
- This study, therefore, explores the acoustic and articulatory implementation of domain-final lengthening in Korean, focusing on the alveolar consonants /t, n/.

Intonational Phonology of Korean

(Jun 1993, 1998)



IP: Intonation Phrase

AP: Accentual Phrase

w: phonological word

s: syllable

T= H, when the AP-initial segment is aspirated or tense C or /h, s/; Otherwise, T= L

%: Intonation phrase boundary tone

The Highest Prosodic Unit in Korean Intonational Phonology

- Utterance not as the highest prosodic unit: There are no acoustic cues that uniquely define an utterance. All utterance-final is an IP-final (Jun 1998).
- Utterance as the highest prosodic unit (Keating, Cho, Fourgeron and Hsu 2003).

- This study included utterance as a prosodic unit to examine whether alveolar consonants show different degree of fronting between in the utterance-final and IP-final positions.

Articulatory experimental study

Methodology

Participants

- Two female native speakers of Korean in their 20s who were born and were raised in Seoul participated in the ultrasound recording.
- We are aiming to record 10 speakers in total.

Stimuli

- Two types of test sentences were created to answer the two main research questions of this study:

  1) Singleton vs. Geminate

  2) The effect of prosodic hierarchy (AP-internal vs. AP-final vs. IP-final vs. U-final)

Stimuli - Singleton vs. Geminate

[t] vs. [tt]

- 그가 얼음을 모으러 가다.
- 그가 얼음을 모으러 갔다.

[n] vs. [nn] /[nd]

- 그가 얼음을 모으러 가나?
- 그가 얼음을 모으러 갔나?

- 미라는 네덜란드에 가다가 왔다.
- 미라는 네덜란드에 갔다가 왔다.

- 미라는 네덜란드에 간다고 하나?
- 미라는 네덜란드에 간다고 한다.

- 냉면 맛없어진 지 꽤 오래됐어요.
- 냉면 맛도 없어진 지 꽤 오래됐어요.

- 무등산에 가보니까 공기가 좋더라.
- 무등산도 가보니까 공기가 좋더라.

8 pairs * 5 repetitions = 90 tokens for each participant

Stimuli - Prosodic Hierarchy on [t]

Prosodic position	Test sentence
AP-final	어제 **보리밭** 갔는데 아직 보리가 안 보이데요.
IP-final	어제 **보리밭,** 갔는데 아직 보리가 안 보이데요.
U-final	어제 어딜 갔다구? **보리밭.**

AP-final	[냉면 **맛**]$_{AP}$ 변한지 오래됐어요.
IP-final	[냉면 **맛,**]$_{IP}$ 변한 지 지 꽤 오래됐어요.
U-final	[뭐가 없다구? 냉면 **맛.**]$_{U}$

Stimuli – Prosodic Hierarchy on [n]

Prosodic position	Test sentence
AP-final	**무등산** 가보니까 공기가 좋더라.
IP-final	**무등산,** 가보니까 공기가 좋더라.
U-final	어디 공기가 좋다구? **무등산.**

AP-final	[아니 5**반**]$_{AP}$ 확실해.
IP-final	[아니야 영미가 3**반,**]$_{IP}$ 영만이는 4반.
U-final	[아니야, 4반도 아니고 5**반.**]$_{U}$

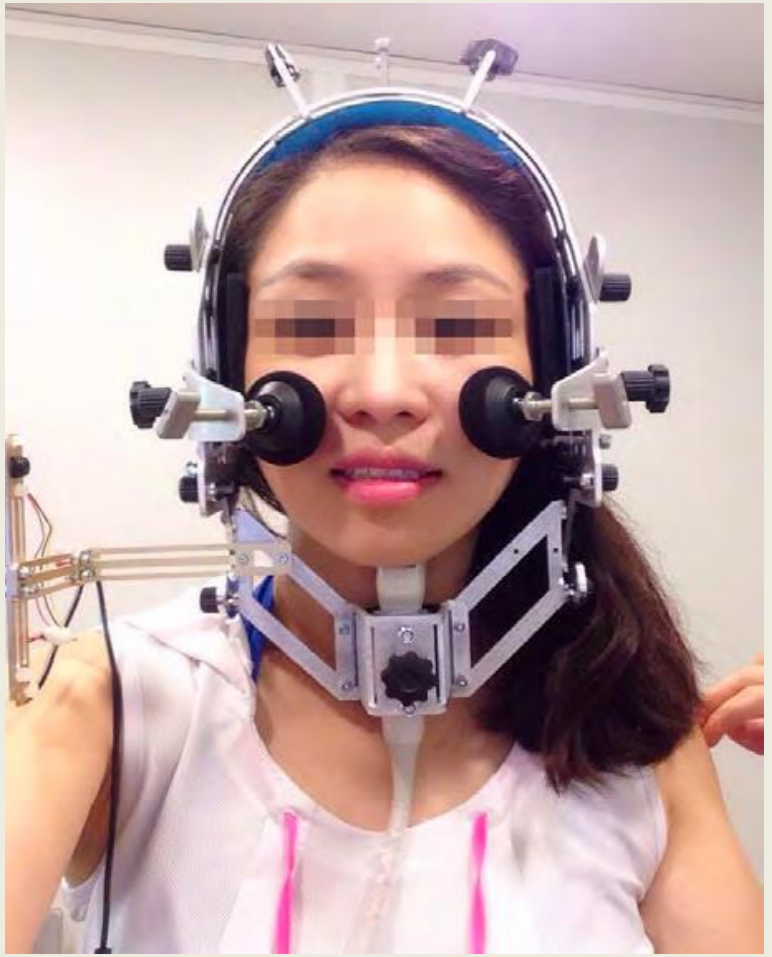
Participants & Procedures

- Midsagittal images of the tongue from the speakers were recorded using an ultrasound machine (A 5-8 MHz convex-curved transducer that produce up to 120 scans per second, 90 degrees field of view (FOV), focal depth of 70mm)

- The probe stabilization headset was used to stabilize the speakers' head.
  - This lightweight and portable headset was used to fix the transducer midsagitally under the speaker's chin. This ensures that there is little lateral movement of the probe and no probe rotation. Nevertheless, the speakers can move freely during the recording because the headset has adjustable parts to help securely fit to the speaker's head.

Procedures

- Once the subjects are seated in the chair, a microphone was attached to the subjects, which enables the simultaneous audio recording.
- Also, the front-view video of the participant’s face was videotaped to record the potential tongue protrusion.
- An audio signal from a microphone and the incoming video signals from the ultrasound machine was automatically synchronized.



Procedures

- The subject was prompted by the experimenter to read aloud the sentences from the sentence list at a comfortable pace.
- The test sentences was presented to the speaker using Articulate Assistant Advanced (AAA) software which records **participants' ultrasound images, videos and acoustic data.**
- The target sentences was repeated five times.

Quantitative analyses

- Quantitative analyses of this study were made on the basis of **three types of data:** `
  i. **durational measures** (temporal expansion)
  ii. **the degree of tongue protrusion** measured from the front-view face video (spatial expansion)
  iii. **tongue shapes** measured from the traced tongue splines from the ultrasound data (spatial expansion)

- All quantitative comparisons were performed on the most extreme point of consonant gestures indicating **the greatest extent of tongue protrusion for each token,** following previous research on interdental articulation (Mielke 2011).

Durational measures

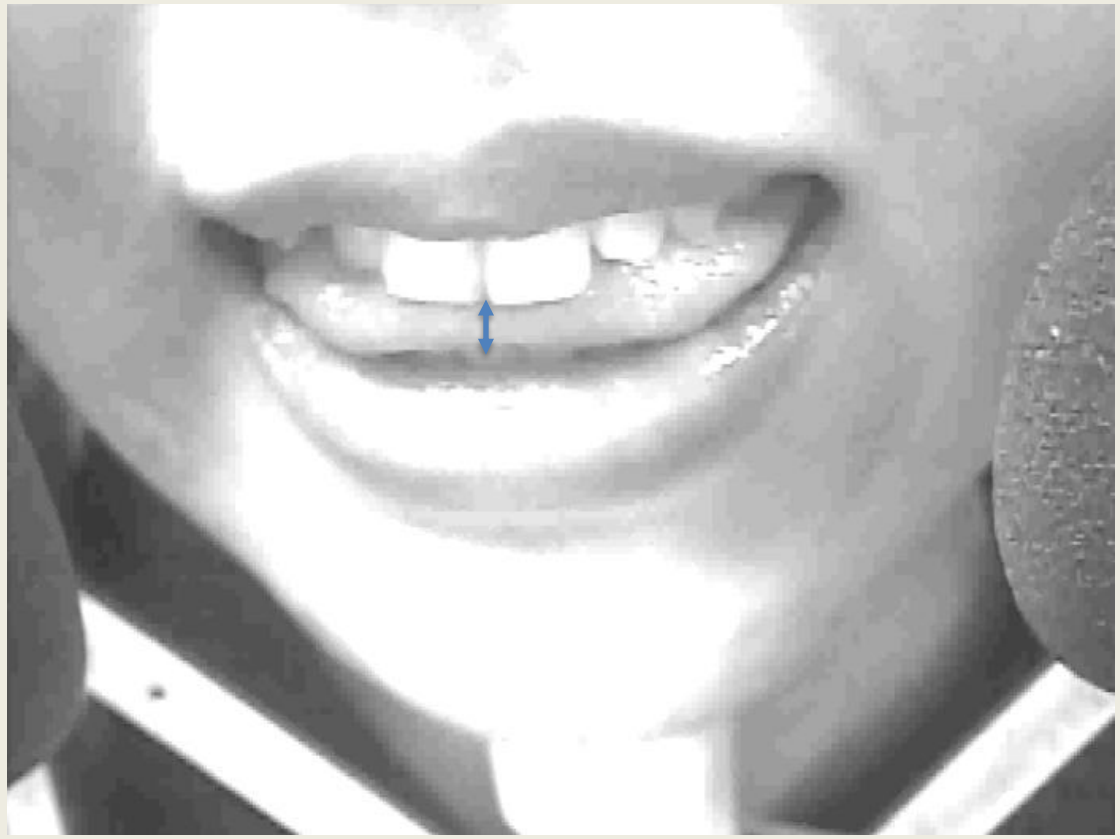
- Segmentation was made on AAA by closely inspecting the spectrogram.
- The duration was measured either using a Praat script or directly on AAA.

Protrusion Distance (PD)

- It would be ideal if we can reliably use the ultrasound data for measurement of tongue protrusion. In many ultrasound images, however, **the tongue tip can often be obscured** by sublingual air or the mandible, or it can be simply **out of view of the ultrasound transducer** because the tongue is extended forward. Therefore, we will **mainly rely on the face video data to quantify tongue protrusion.**

Protrusion Distance (PD)

- Following Mielke et al. (2011), **tongue protrusion** was measured as **the distance between the tongue tip and a reference point** (across all tokens) (e.g. **the lowest point of upper teeth**) using a built-in ruler of AAA.



Mixed-effects linear regression

- Mixed-effects linear regression models will be used to examine the effects of prosodic boundaries on the protrusion distance at various prosodic positions.

  - DV: Protrusion Distance (PD)
  - Predictors:
    - Intervocalic singleton vs. geminate
    - Prosodic position (AP-final, IP-final, U-final)
    - Duration

Mixed-effects linear regression

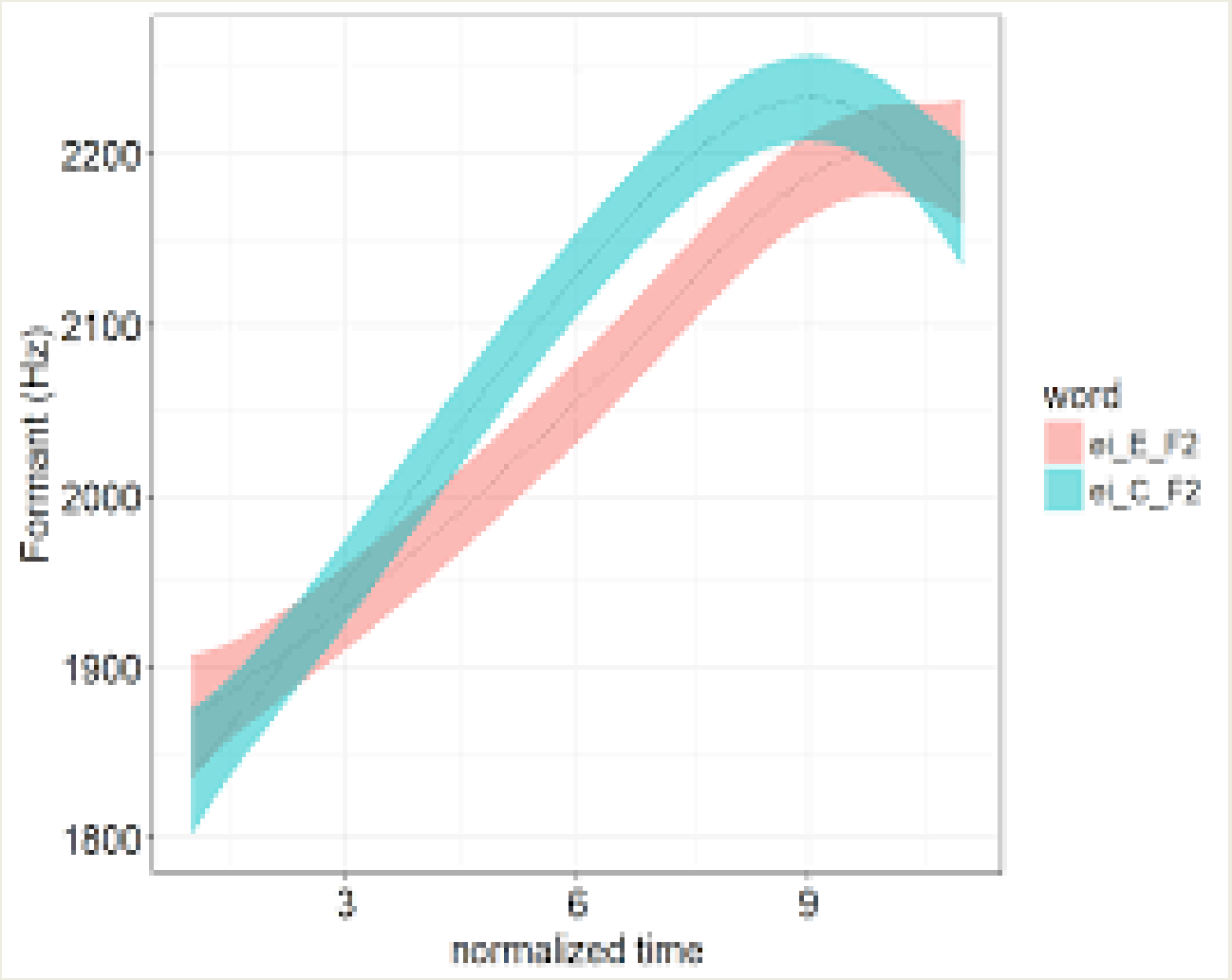
- Using the *lmer* function from the lme4.0 package in R (R Development Core Team 2018), models were fit to the magnitude of tongue gestures, with the SPEAKER and ITEM as potential **random effects** that account for different behavior by individual speakers and different test items.
- Model selection will be guided by **log likelihood tests** as well as Akaike Information Criterion (Akaike 1974) and Bayesian Information Criterion (Schwarz 1978) values.
- Significance levels or **p-values** will be calculated based on Satterthwaite's (1946) approximations for the degrees of freedom using the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2013).

SS-ANOVA

- To trace tongue contours in the ultrasound images, AAA was used. The **tongue contours** were extracted in a series of **x-y coordinates.**
- Tongue contours were compared using the **smoothing spline-ANOVA** (SS-ANOVA; Davidson 2006; Gu 2002), **a statistical technique for comparing curve data**, to determine whether two sets of curves are significantly different.

SS-ANOVA

- In the SS-ANOVA test, smooth lines are generated for each set of curves as **the average contours** of the subset of tokens of interest. Then **Bayesian confidence intervals of 95%** are calculated and plotted around the curves.
- The sets of curves are **considered to be different** in areas where **the confidence intervals** for the two sets have **no**

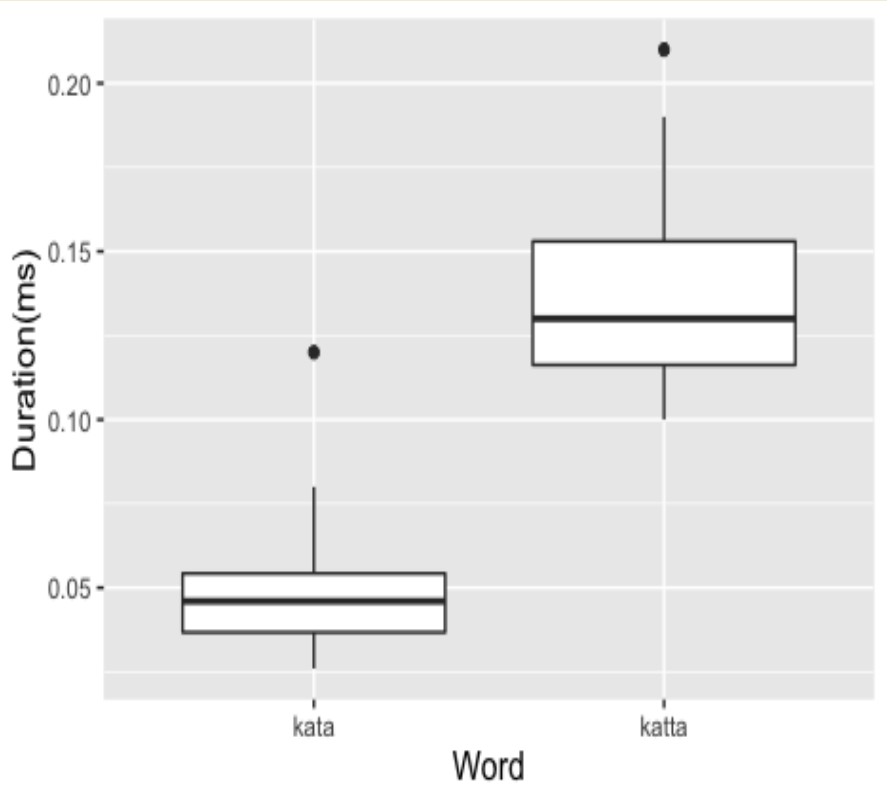


Results

I. Singleton vs. Geminate

Duration: Singleton vs. Geminate

[t] vs. [tt] (e.g. 가다 vs. 갔다)



[n] vs. [nn] (e.g. 가나 vs. 갔나)

Tongue Protrusion

[t] in kata 가다

[tt] in katta 갔다

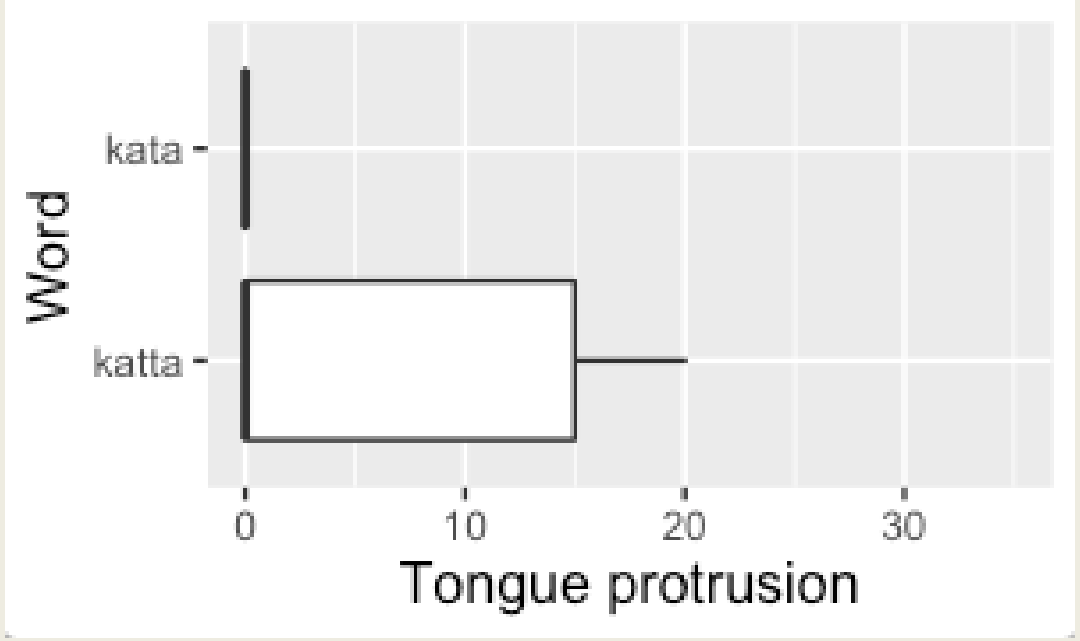
Tongue Protrusion

[n] in kana 가나

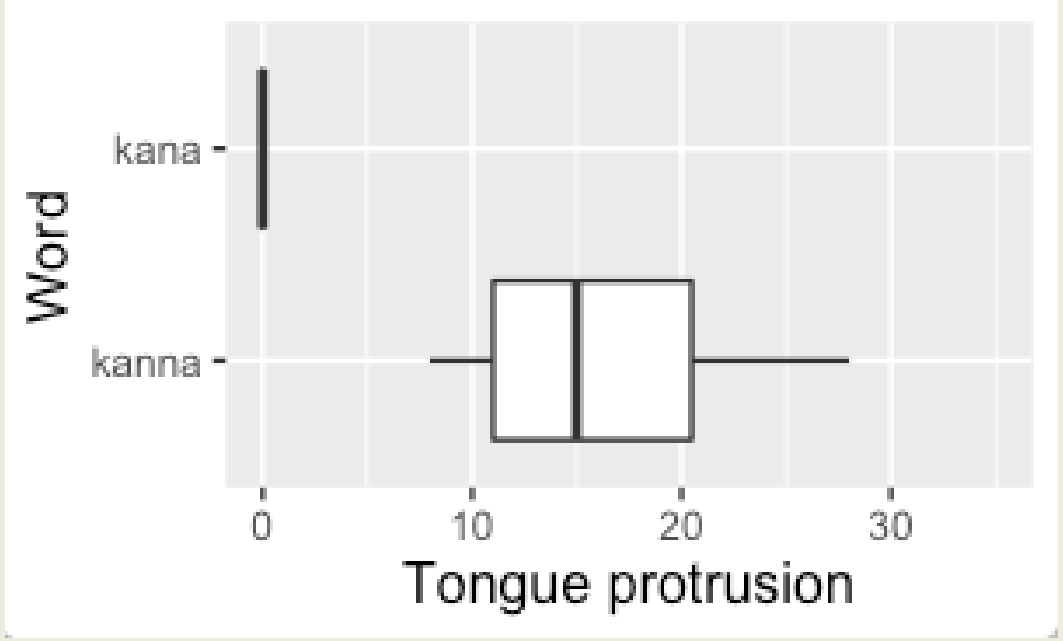
[nn] in kanna 갔나

Protrusion Distance (PD)- Singleton vs. Geminate

[t] vs. [tt] (e.g. 가다 vs. 갔다)



[n] vs. [nn] (e.g. 가나 vs. 갔나)



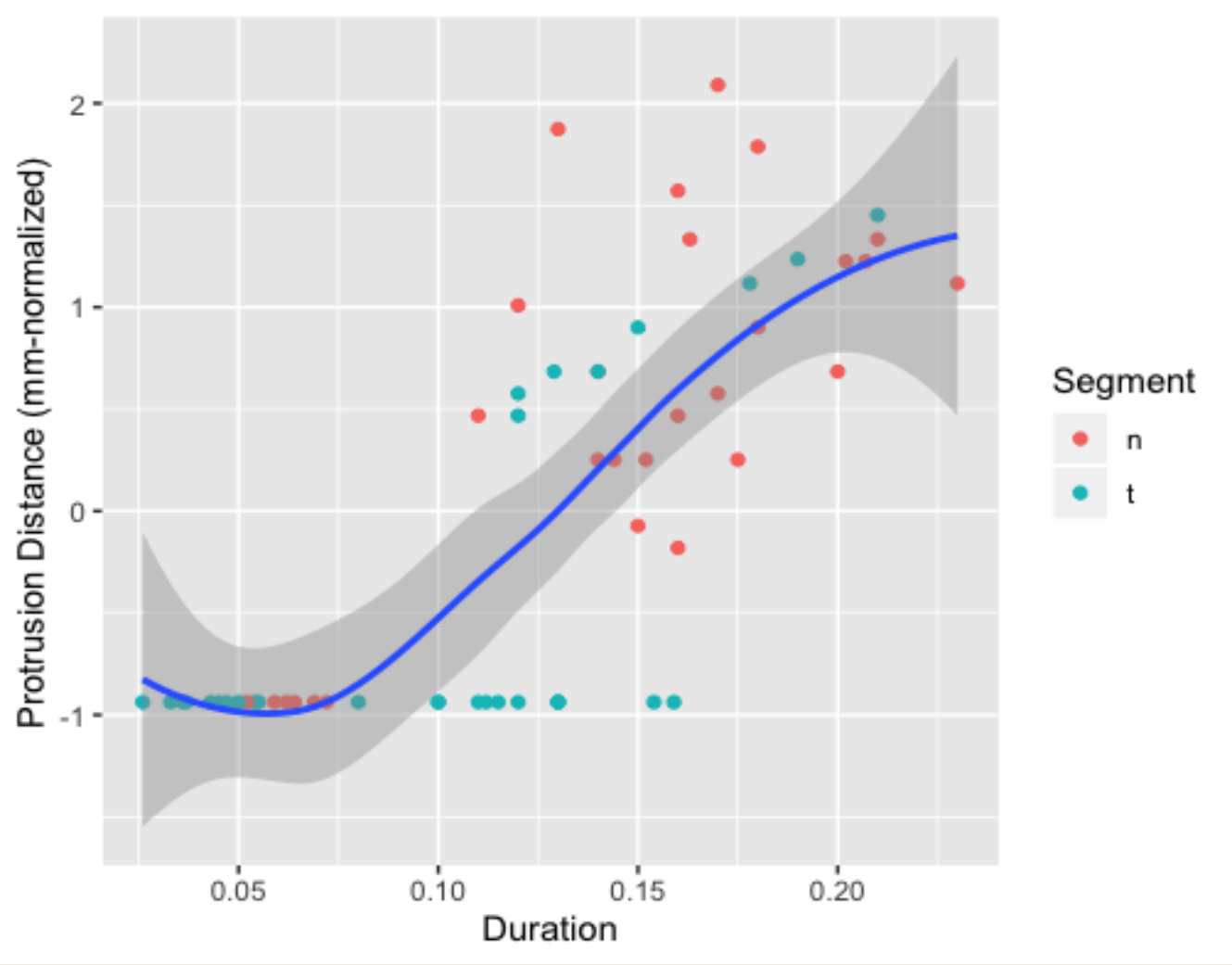
Coefficient table

Factors	Estimate	Standard Error	t-value	p-value	
(Intercept)	16.473	2.017	8.166	1.61E-08	***
Segment - t (vs. n)	-8.906	3.007	-2.962	0.006617	**
Consonant-Singleton (vs. geminate)	-16.473	4.357	-3.78	0.000869	***

cf. lmer(ProtrusionDistance~Segment+Consonant+(1|SUBJECT)+(1|ITEM))

- **Tongue protrudes more for [n, nn]** compared to [t, tt].
- The interaction between Segment (n vs. t) and Consonant type (singleton vs. geminate) was not significant. -> **Both for [n] and [t], tongue protrudes significantly more for geminate** consonants compared to singleton counterparts.

Correlation between Protrusion Distance & Duration



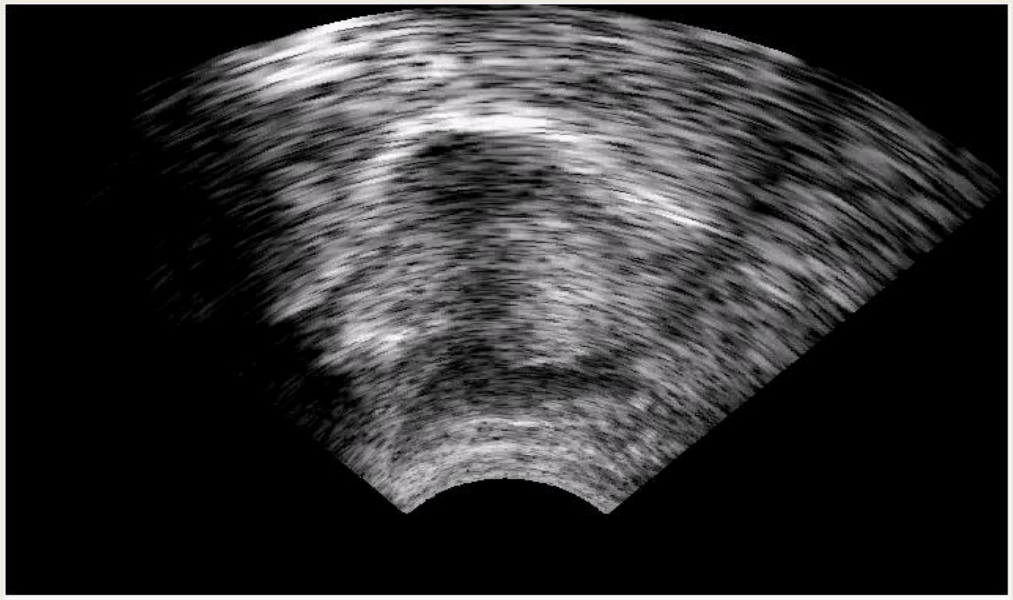
- Correlations are measured using R's *cor.test* function, which provides the values of Pearson's *r* as well as *p*-values (R Core Team 2018).

- A strong positive correlation between Protrusion Distance and the duration of consonants, with a Pearson's value of r=0.758 (p= 1.898e-06***).

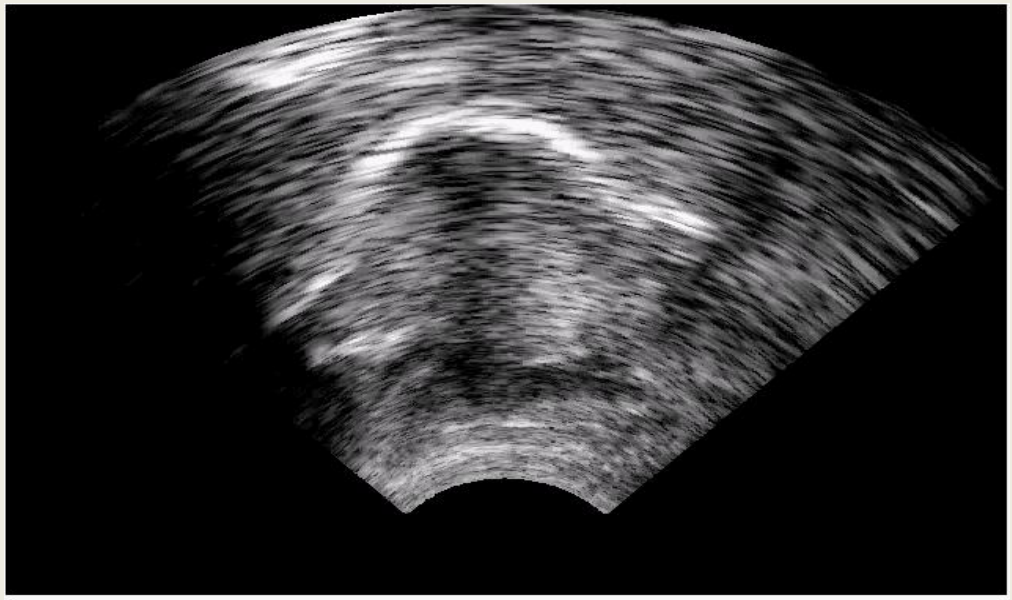
[Tongue movements]

Articulation of singleton [t] vs. geminate [tt]

가다 [t]

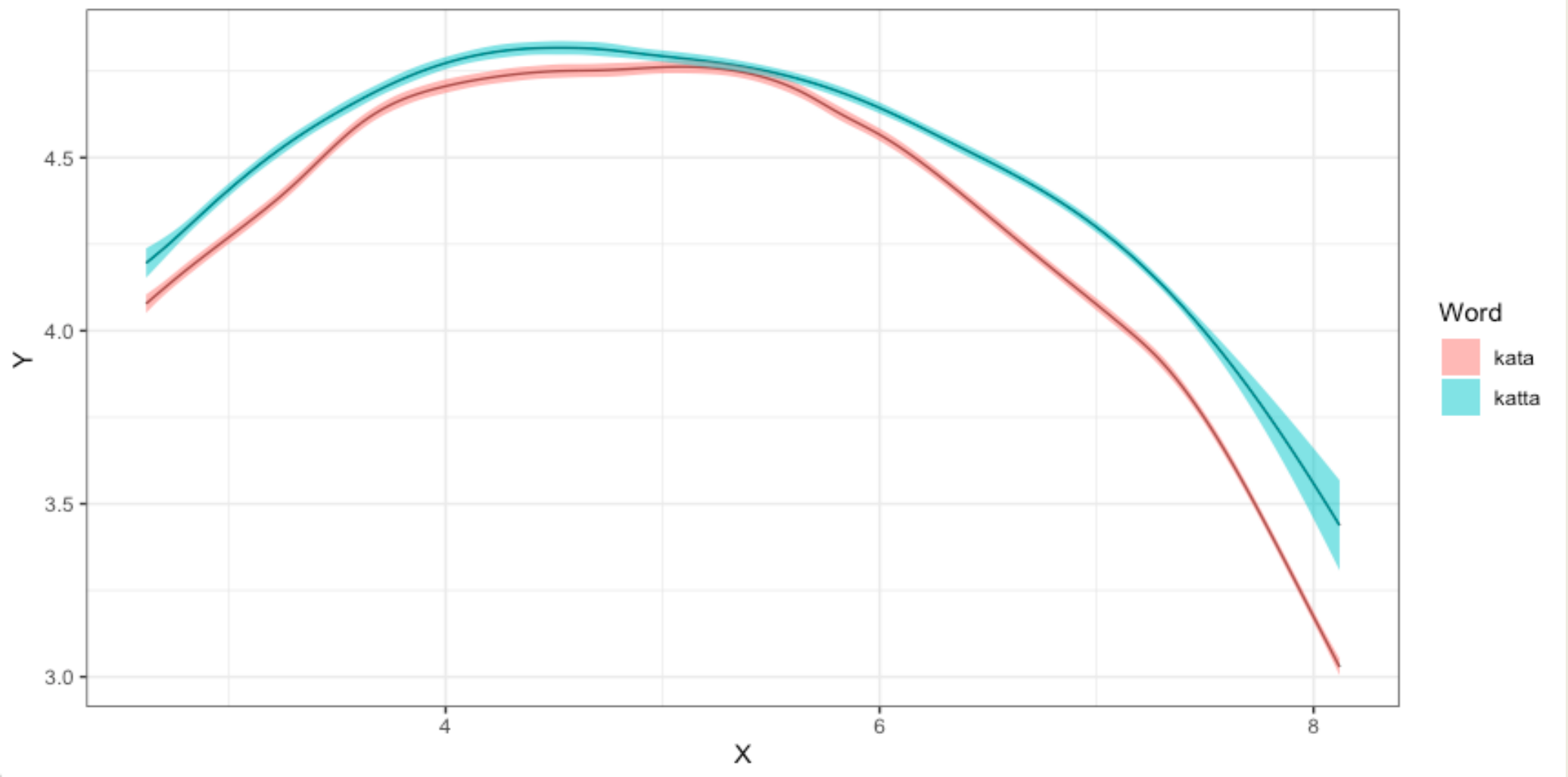


갔다 [tt]



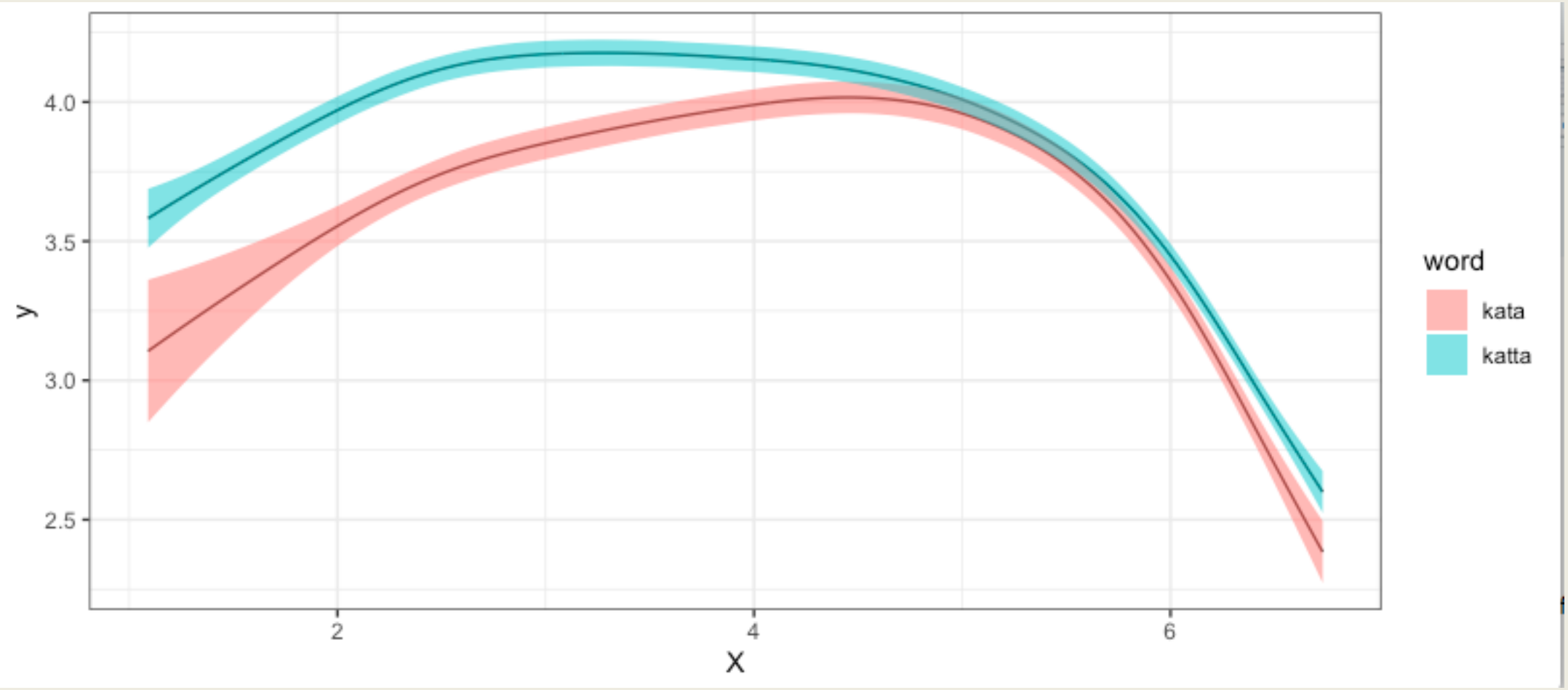
[Tongue splines]

Articulation of [t] vs. [tt] - Sub1



[Tongue splines]

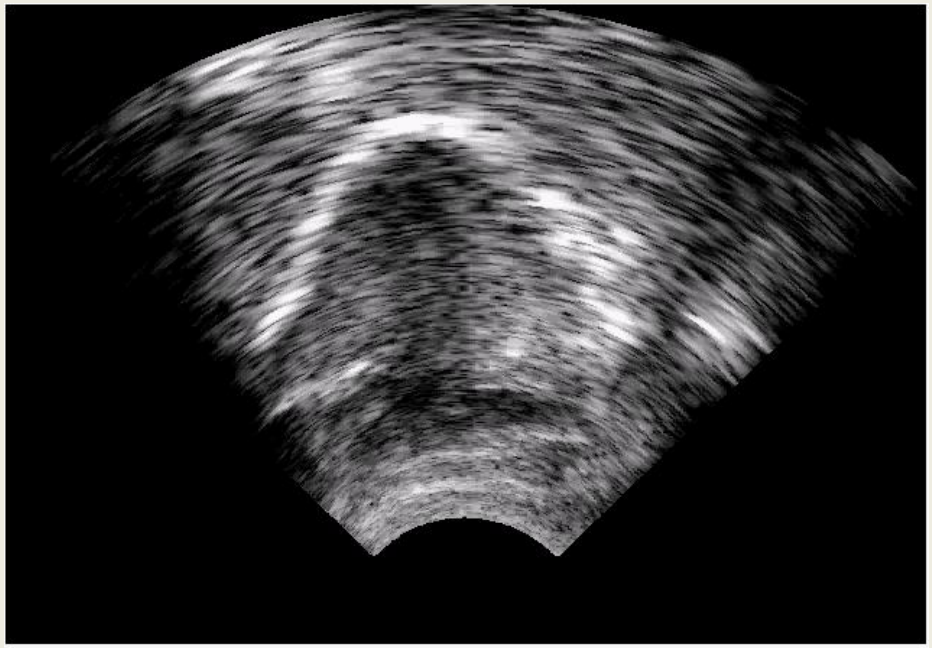
Articulation of [t] vs. [tt] - Sub2



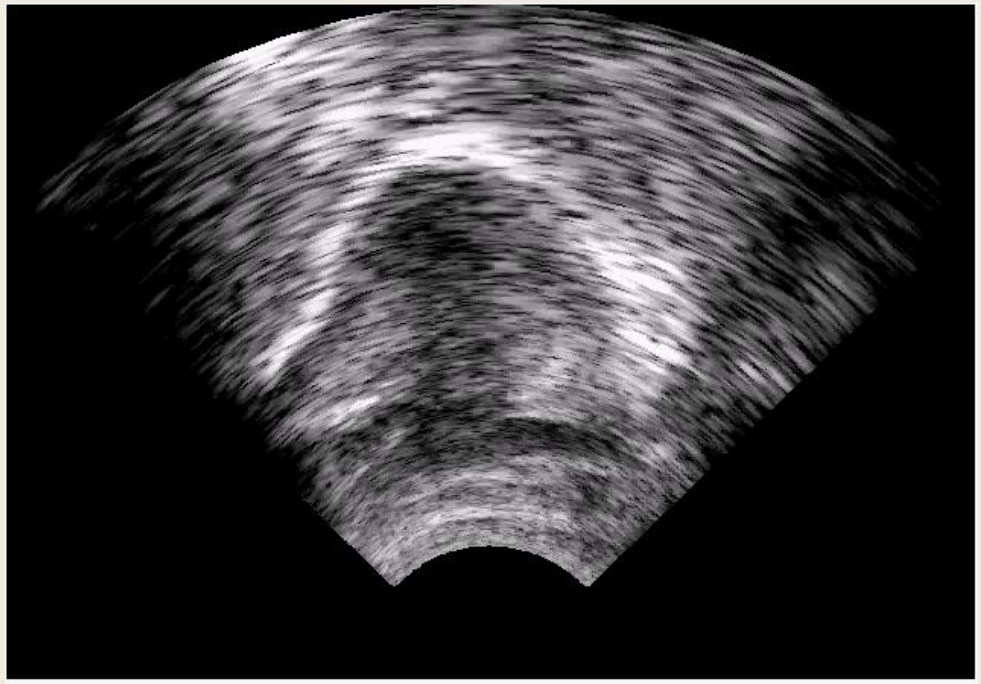
[Tongue movements]

Articulation of singleton [n]

가나 [n]

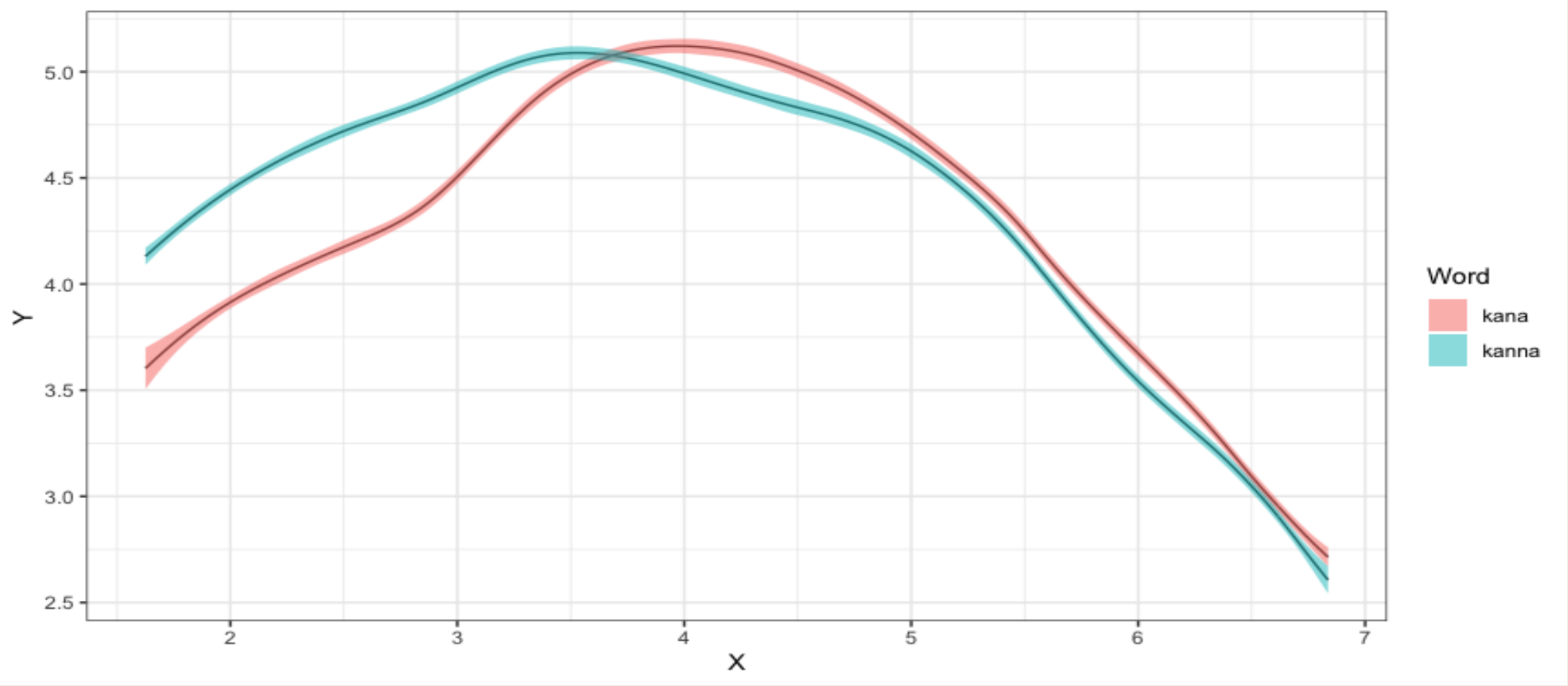


갔나 [nn]



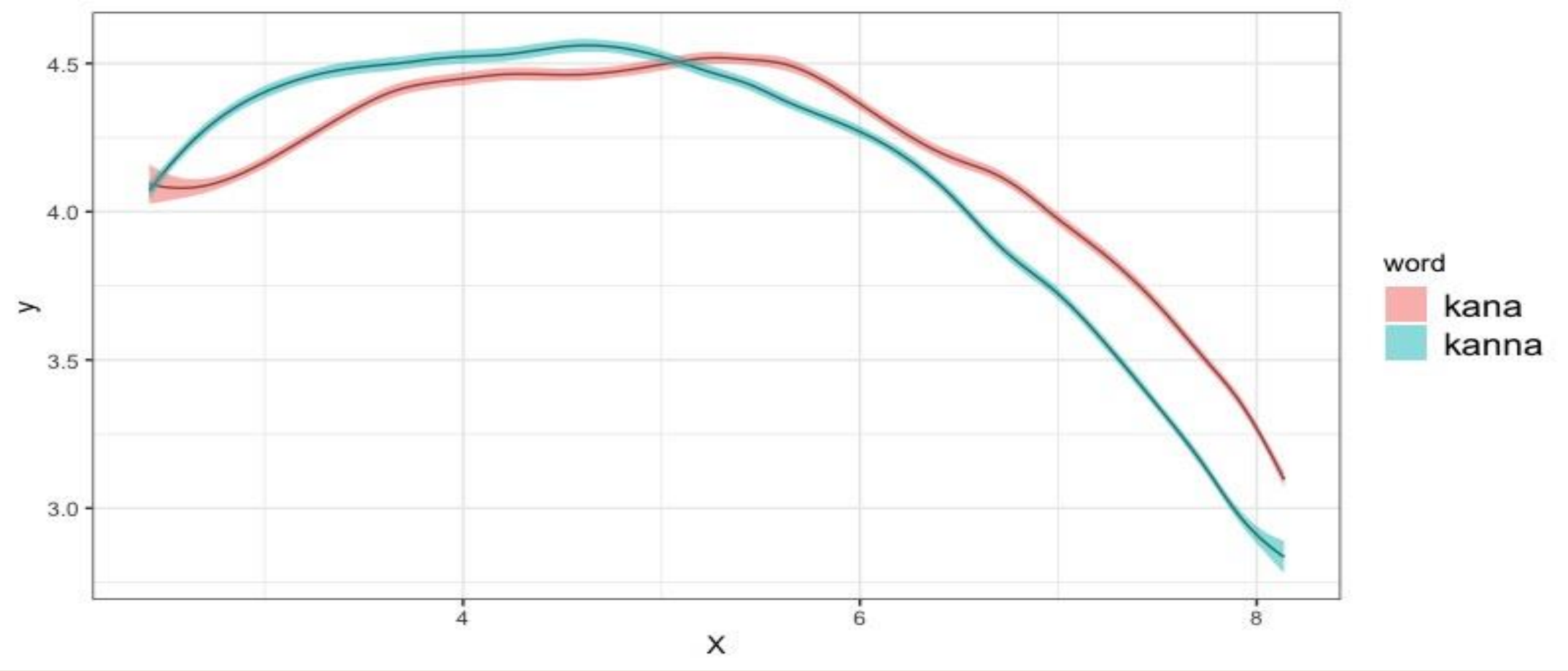
[Tongue splines]

Articulation of [n] vs. [nn] - Sub1

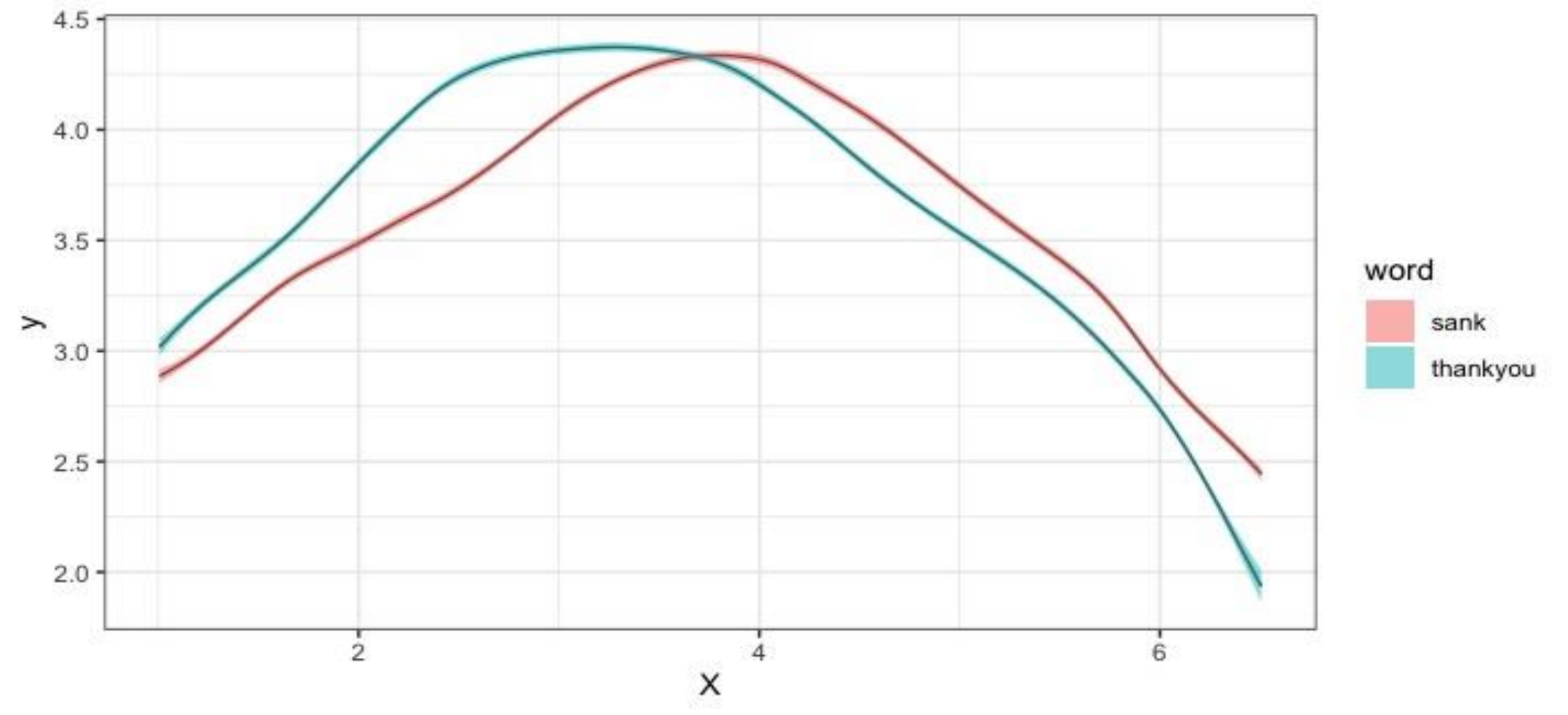


[Tongue splines]

Articulation of [n] vs. [nn]



English interdental
[s] vs. [θ]

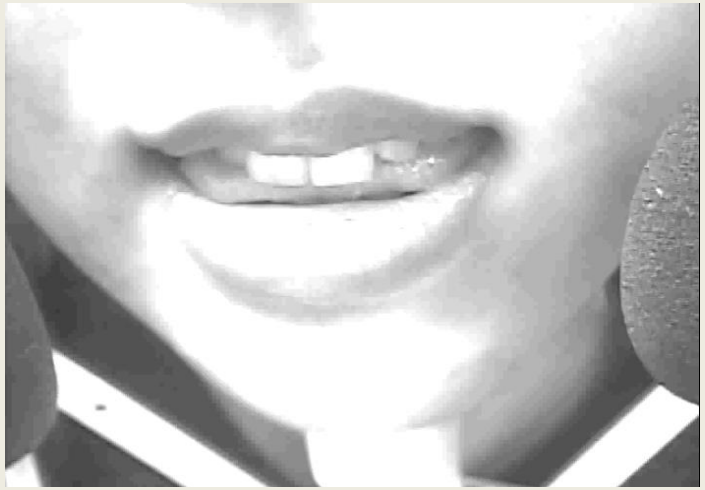


II. The effect of prosodic hierarchy

Tongue Protrusion

AP-final [t]

IP-final [t]

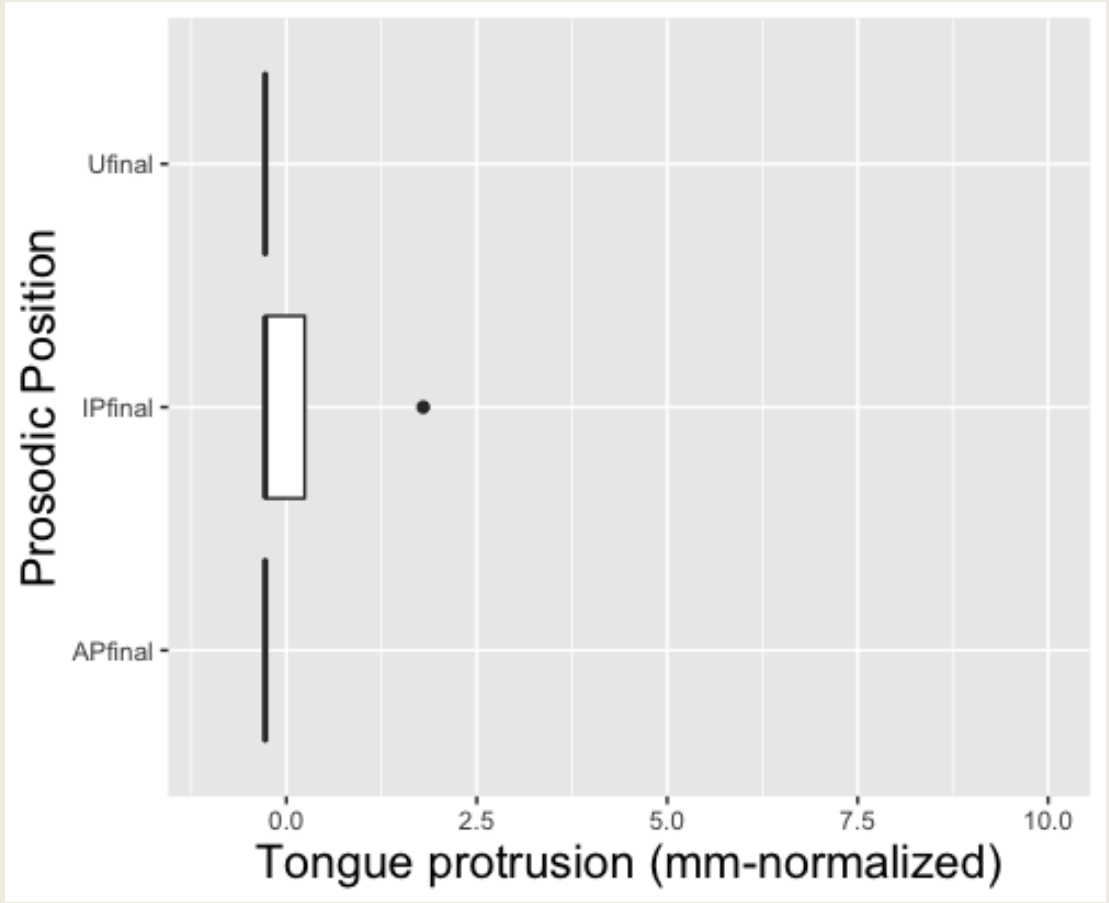


U-final [t]

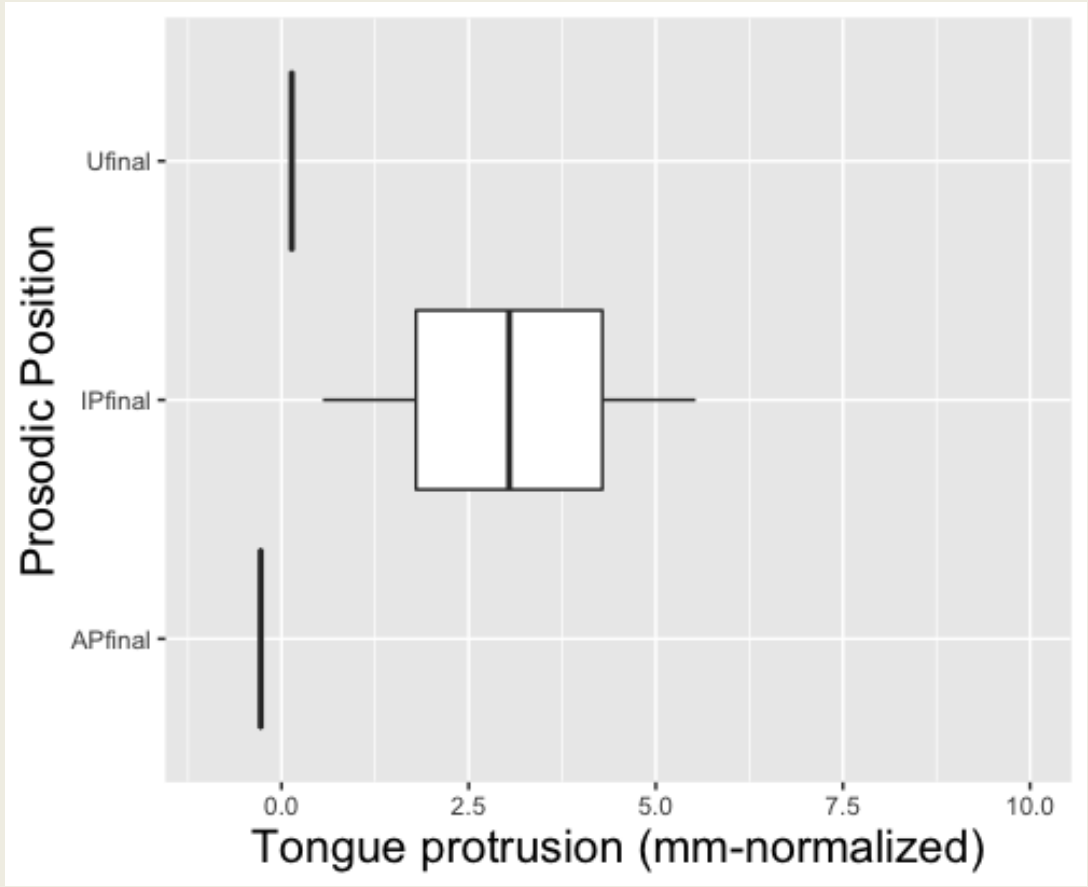
Prosodic position	Test sentence
AP-final	어제 **보리밭** 갔는데 아직 보리가 안 보이데요.
IP-final	어제 **보리밭,** 갔는데 아직 보리가 안 보이데요.
U-final	어제 어딜 갔다구? **보리밭.**

Protrusion Distance (PD)- Singleton vs. Geminate

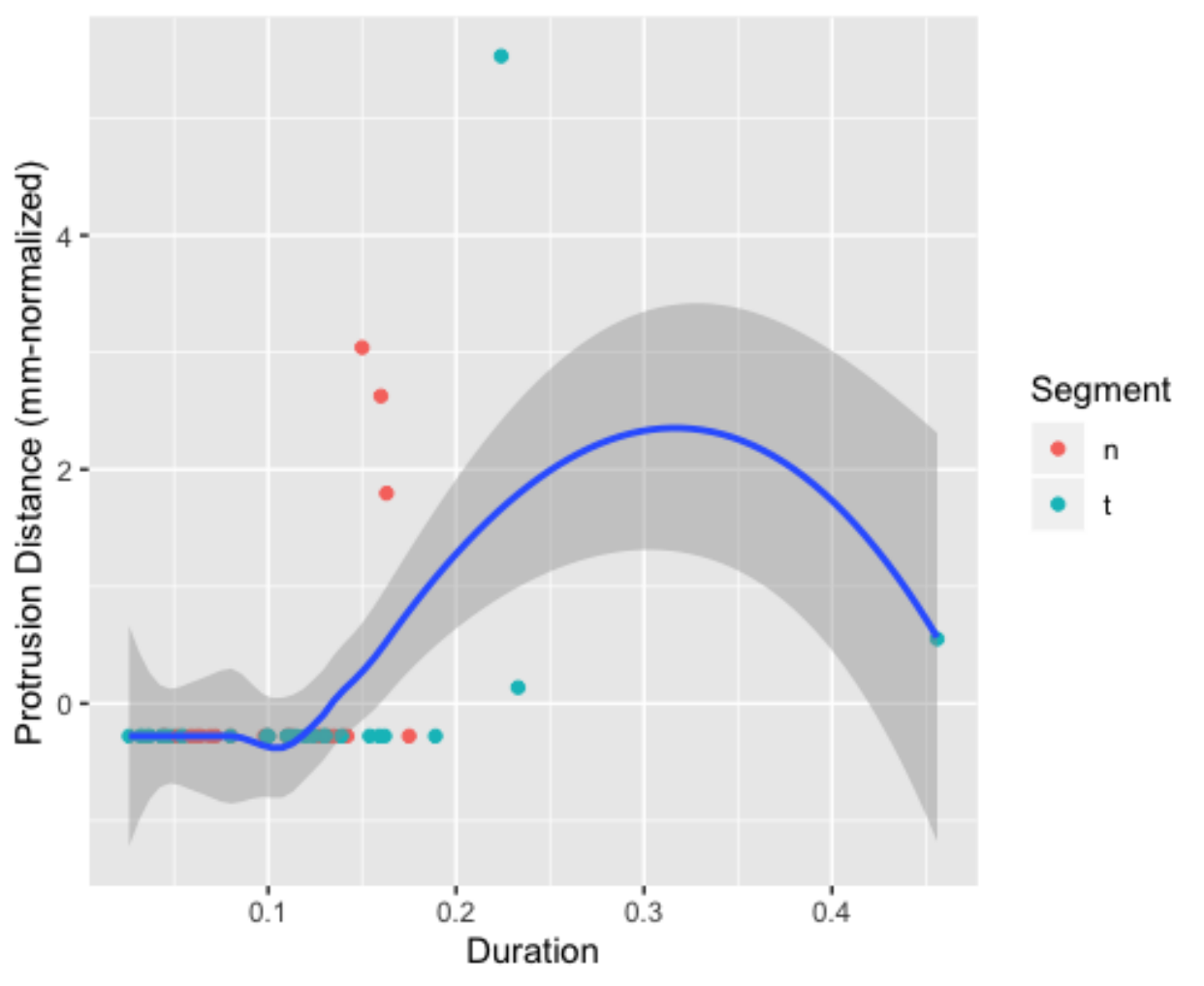
[t]



[n]

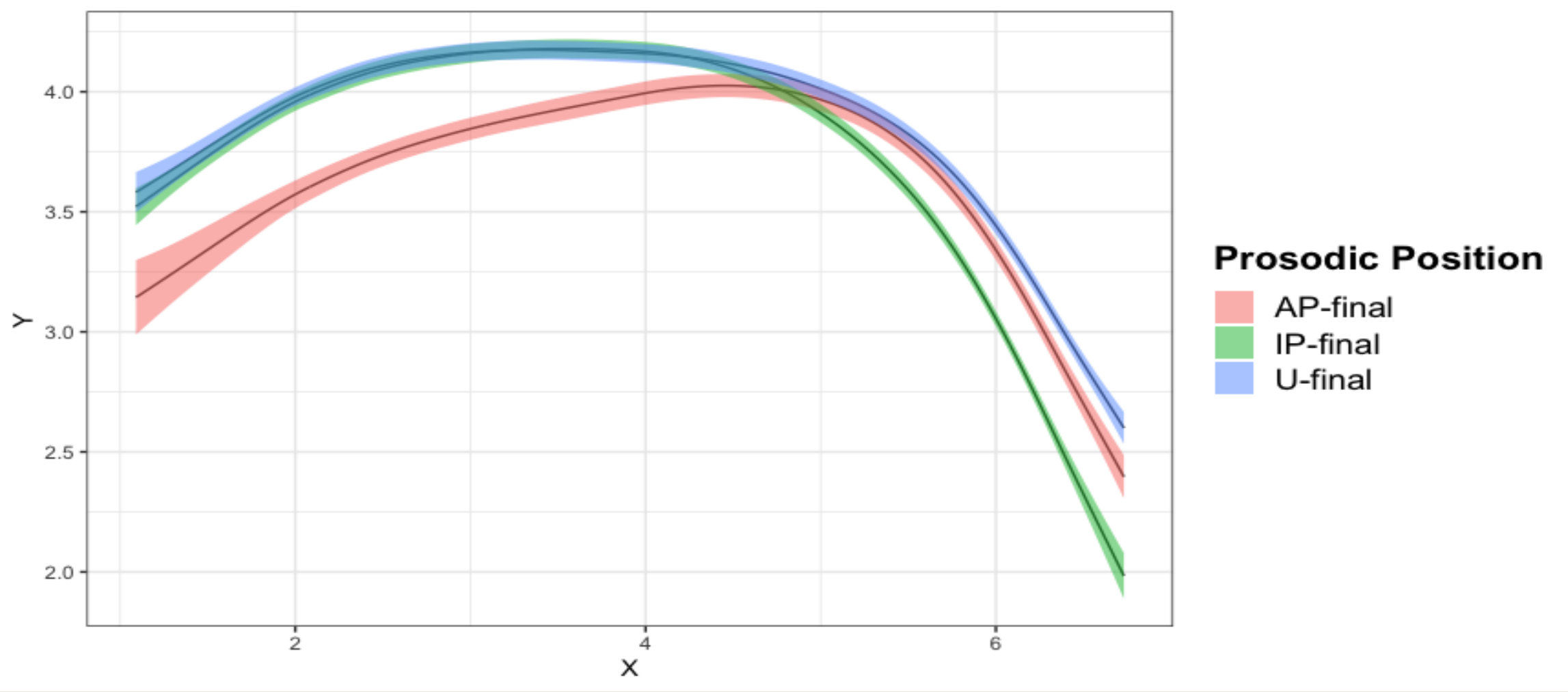


Duration & Protrusion Distance for phrase-final consonants

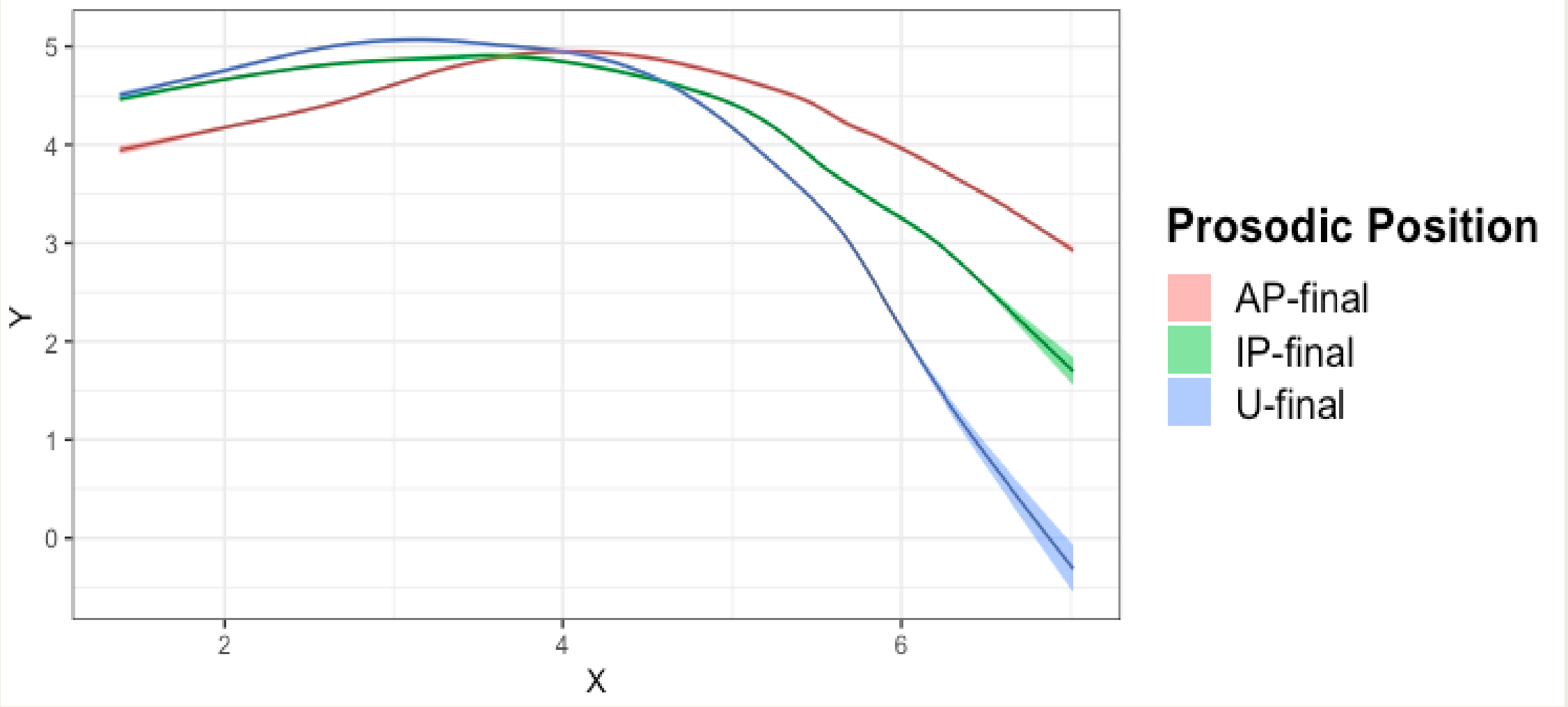


- No significant correlation between Protrusion Distance and the duration of consonants, with a Pearson's value of r=0.345 (p= 0.09909).

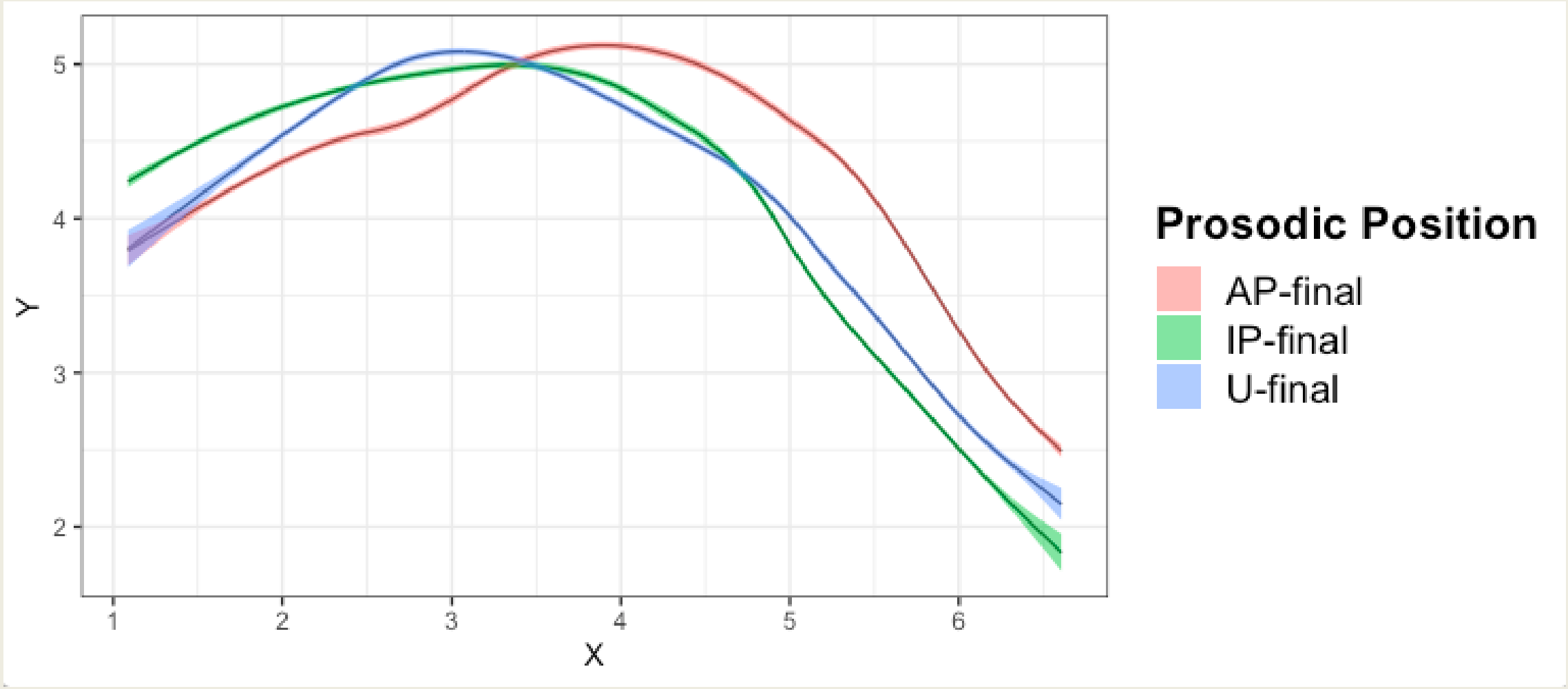
The effect of prosodic hierarchy on tongue splines for [t] - Subject 1



The effect of prosodic hierarchy on tongue splines for [t] - Subject 2



The effect of prosodic hierarchy on tongue splines for [n] - Subject 1



Summary

1. The results of this study confirm that alveolar consonants /t, n/, when geminated, exhibit tongue fronting and raising to the extent that the tongue tip is protruded from the mouth, which is accompanied by the extremely prolonged duration corresponding approximately to three times longer than the duration of the singleton counterparts.

Summary

2. The prosodic domain-final lengthening is observed for alveolar consonants in Korean.

- This phonetic effect is mainly implemented by significant tongue raising and slight tongue fronting for phrase-final alveolar consonants in Korean.
- Tongue protrudes from the mouth only when the duration of phrase-final singleton alveolar consonant is long enough.
- The duration of singleton phrase-final singleton alveolar consonant, however, tend not to be as long as that of geminates.

Summary

	Fronting	Tongue Protrusion	Raising
Gemination	Yes	Yes	Yes
Domain-final lengthening	Yes	Largely no	Yes

Discussion

Phonetic correlates of geminations

- The core feature of geminates that distinguish them from their singleton counterparts is their **longer duration.**
- **The singleton-geminate duration ratio** is not universal but **language- specific** and **varies by** which **segment** the geminate consist of.
  - Quite **a wide range of duration ratio** has been found thus far: **from 1:1.5 in Madurese** (Cohn et al. 1999) to **1:2.9 in Turkish** (Lahiri & Hankamer 1988).
  - For **Guinaang Bontok**, the highest ratios, i.e. the longest geminates, can be found with **nasals** (ratios between 1:1.72 and **1:2.15)**, followed by **lateral** approximants (ratio: 1:**2.0**), **stops** (ratios between 1:1.81 and **1:1.90**), **approximants** (ratios between 1:1.56 and **1:1.69**) and **fricatives** (ratio for [s]: **1:1.56**). The lowest ratio is found for **glides** (ratio: 1:**1.39**) (Aoyama & Reid 2006).

Phonetic characteristics of morphological geminates

- While the duration of **lexical geminates** is significantly longer than their singleton counterparts, facts are **less clear** with **morphological geminates.**

- **Morphological geminates** have been investigated **less extensively than lexical geminates**, and there are only **a handful of empirical studies** on the phonetic characteristics of morphological geminates.

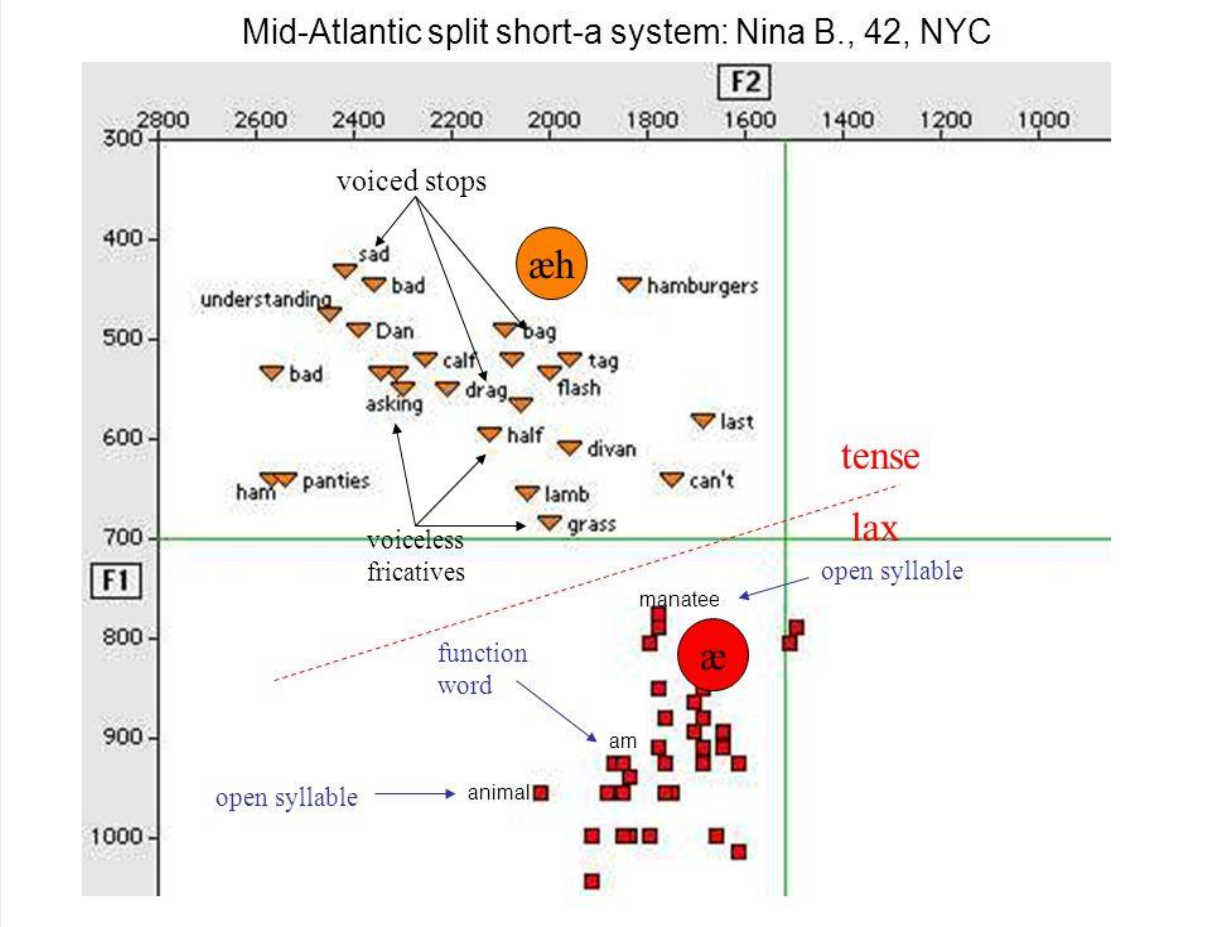
- **Lexical geminates tend to be longer than** morphological geminates, which signals the **higher boundary strength of lexical geminates** (Hedia, 2019)

Phonetic characteristics of morphological geminates in Korean

- The preliminary results of this study revealed that **the singleton-geminate duration ratio in Korean** is quite large ([t]: [tt]=**1: 2.9**; [n]: [nn]=**1: 2.97**).
- **The large duration ratio for morphological geminates** in Korean is quite striking.
- This study presents **novel articulatory evidence** that gemination may involve **the change in the place of articulation.**
- It is conceivable that when the scale of **temporal expansion** is extremely large, the gemination may result in **a spatial expansion** involving the changes in the place of articulation.

Short-a tensing in English

- **An ongoing change** in North America (Labov, Ash, and Boberg, 2006)
- **Lax /æ/** become **tense (raised, fronted, and occasionally diphthongized) /æh/.**
- The phonological, morphological and lexical conditioning factors vary by regions.
- **The most widespread short-*a* system** in North America is **the nasal system** characterized by the wide separation between tense /æh/ before nasal consonants and lax /æ/ elsewhere.



Nasality & Tensing

- The effects of nasalization have the primary impact on the vicinity of the F1 (Ohala 1974; Wright 1975; Beddor 1982; Chen 1997).
- Acoustically, movements of the velum that result in nasalization alter vowel height, resulting in a significant F1 lowering in the vowel spectrum.
- Also, the perception of vowel height can be influenced by nasalization. The low nasal vowels are perceptually raised and the high nasal vowels perceptually lower (Wright 1975; 1986).
- When two adjacent peaks in a vowel spectrum are close in frequency, listeners determine vowel quality based on some weighted average of the two peaks, or center of gravity, and they have difficulty in determining the contribution of oral tract configuration and velopharyngeal coupling to the spectral shape of a nasal vowel. An extra nasal peak in the region associated with vowel height results in a shift in the perceived height of nasal vowels (Goodin-Mayeda 2011).

A change in progress in Korea?

- Kim (
- Kong ()

Universals of domain-final lengthening

- The preliminary analyses of this study presents articulatory evidence showing that progressively **stronger prosodic boundaries** result in **increasing amounts of lengthening and articulatory strengthening** for consonant gestures.
- They confirm the previous findings showing **that final lengthening is governed by the size of the prosodic boundary**, in that the lengthening becomes gradually longer as the prosodic boundary becomes higher (i.e., IP final vowels are longer than Wd final vowels) (Cho and Keating 2001, *inter alia*).

Language-specific patterns for domain-final lengthening

- The patterns of domain-final lengthening **differs by languages.**
  - For stress-timed languages such as English (Turk & Shattuck-Hufnagel, 2007) and German (Kohler, 1983), the patterns for domain-final lengthening interacts with prominence (lexical stress).

- It has been widely established that, regardless of stress, **the final vowel** located nearest to the phrasal boundary is the most heavily influenced by final lengthening (Berkovits, 1993; 1994; Byrd, 2000; Turk & Shattuck-Hufnagel, 2007).

Language-specific patterns for domain-final lengthening

- But other units such as **final consonants, final VC's, final syllables, and final words** have been identified as subject to domain-final lengthening as well.
  - In **Hebrew, the duration of the final consonant was longer** than that of the final vowel (Berkovits 1993; 1994).
  - In **Korean, the final vowel**, preceding the coda consonant, **had the longer duration** (Baek 2017).

Domain-final lengthening for consonantal gestures

- Relatively **less attention** has been paid to the lengthening for **consonantal gestures themselves.**
- Varying strengths of prosodic boundaries have distinct degrees of **lengthening of the boundary-adjacent consonant gestures** (Byrd and Saltzman 1998).
- The results of this study provide **novel experimental evidence of entire tongue configurations for consonantal gestures** structurally conditioned by prosodic hierarchy.

Implications for prosodic hierarchy of Korean

- The results of this study confirm that prosodic boundaries of varying strengths are active in determining temporal aspects of speaking in Korean.
- What is rather controversial, however, is **the highest prosodic level in Korean.**
  - Utterance as the highest prosodic unit (Keating, Cho, Fourgeron and Hsu 2003).
  - Utterance not as the highest prosodic unit: there is no acoustic cue that uniquely defines an utterance. All utterance-final is an IP-final (Jun 1998).
- The results of this study therefore **lend support to Jun's (1998)**, providing no significant evidence for Utterance as the highest prosodic level in Korean.

THANK YOU!

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